ΔG and $\Delta\overline{\mathrm{q}}$ measurements at PHENIX

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Abstract. RHIC provides a unique opportunity to address the components of the proton spin. In comparison to deep inelastic scattering experiments, the gluon is the main player in proton-proton collisions. PHENIX has measured double spin asymmetries of various processes. Those contain the information of the gluon spin component (ΔG). In addition high energy collisions open the unique channel to access flavor dependent information of quark polarization through the real W boson production. Because of the feature of weak interaction, the parity violating process defines the helicity of quarks in the interaction. The single spin asymmetry is the observable. It is especially interesting to probe anti-quark components ($\Delta\overline{\mathrm{q}}$). In this article, we report the recent progress of ΔG and $\Delta\overline{\mathrm{q}}$ measurements at PHENIX.

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INTRODUCTION

Quarks are always hidden in composite forms with gluons. The composite form is called hadron. The proton is the unit of all matters, and also the most common hadron. The question about how the proton is build is very fundamental in the law of the nature. To answer the question, it was started with deep inelastic scattering (DIS) experiment. The DIS experiment was evolved to utilize polarized lepton beam to investigate the proton spin components. A complementary approach is to collide polarized protons. RHIC at Brookhaven National Laboratory is the world's only polarized proton-proton collider. The center of mass energy is up to $\sqrt{s} = 500$ GeV. PHENIX, one of two large multipurpose detectors at RHIC, has measured spin asymmetries of particle productions, which is to probe the gluon polarization in the proton (ΔG) and the flavor decomposition of anti-quark spin component ($\Delta\overline{\mathrm{q}}$). While the proton spin sum rule is applied to the integral, experiments can only access to a certain range of partonic momentum fractions. In this article, we use $\Delta g(x)$ and $\Delta q(x)$ for gluon and (anti-)quark when we discuss about its functional form of the partonic momentum fraction. Here the first moment, $\int_0^1 \Delta g(x)dx$, is ΔG.

In polarized DIS, there is a complexity of extracting the gluon contribution in the reaction, because the process goes through $q\bar{q}$ pair. $\Delta g(x)$ also appears in the Q^2 evolution behavior, but it needs to cover a large kinematic range. In polarized proton-proton collisions, $\Delta g(x)$ appears directly in the spin asymmetry measurements.

Analyses of polarized semi-inclusive DIS experiments [1, 2, 3] have determined the individual flavor separated quark and anti quark helicity distribution (Δq and $\Delta\overline{\mathrm{q}}$) by connecting final state hadrons with quark flavors using fragmentation functions. Colliding polarized protons is a complementary way. At the collider energy, the real W boson is produced via a parity violating weak process, which enables to identify the quark flavor and helicity in the proton contributed to the process by detecting decay leptons without the uncertainty of fragmentation functions. Another advantage is, because the scale is set by the heavy mass of the W boson, higher order perturbative quantum chromodynamics (pQCD) corrections can be evaluated reliably.

THE PHENIX EXPERIMENT

The PHENIX detector has been described in detail elsewhere [4]. The central arm spectrometer covers $|\eta| < 0.35$ in pseudorapidity and $\Delta\phi = 2 \cdot \pi/2$ in azimuth. The muon arm spectrometers cover $1.2 < |\eta| < 2.2$, and the forward electromagnetic calorimeter (MPC) was installed in 2006 covering $3.1 < |\eta| < 3.9$. The luminosity is monitored by beam-beam counters, those are two arrays of 64 quartz Čerenkov counters each located at $3.1 < |\eta| < 3.9$. Their coincidence rate is connected to the luminosity from the van der Meer scan technique [5].

In high rate proton-proton collisions, events are selected with the level-1 trigger. In the central arm, the electromagnetic calorimeter (EMCal) and the ring image Čerenkov detector are segmented into about 200 small units and the fast signal from each unit are got through a look-up table to produce a trigger. In the muon arm, a combination of hits in between steel absorbers was used to make a track road for the trigger. Recently a new trigger system based on track momentum was implemented.

At RHIC, the key feature to reduce the systematic uncertainty is in the bunch structure of the proton beams. They consist of 120 bunches and the revolution time is 1.2 micro seconds. Each bunch is assigned a different polarization direction. By using alternating combinations of polarization directions, we can reduce the systematics of detector instability in the asymmetry measurement.

SEA QUARK MEASUREMENTS

There are two W boson programs at PHENIX. One is to detect electrons of W boson decay in the central arm and the other is to detect muons in the muon arm. Because of the large mass, the W boson produces a high momentum lepton. In the mid-rapidity region, it results in a high p_T lepton which helps to separate the signal from backgrounds.

From the data set of 2009 run, the electron signal is confirmed and reported with the integrated luminosities of $\int L dt = 8.6$ pb^{-1} [6]. Figure 1 shows the transverse momentum spectra of the electron and positron candidates, where the signal of W boson decay is seen at $M_W/2$ on the slope of QCD background. Backgrounds are mainly from misidentification of charged hadrons and early conversion of photons from high momentum neutral pions. The production cross section of W boson is measured and consistent with the standard model theoretical calculation. After applying an isolation cut to improve the purity, the W boson signal ($30 < p_T < 50$ GeV) is sorted by the proton spin direction. Figure 2 shows the parity violating single spin asymmetries (A_L). At this stage the uncertainty is still too large to separate various theoretical models.

The new muon arm trigger system is based on the momentum. It was operational for the first time in 2010. The analysis is on-going and the detail is reported in these proceedings.

For the next few years, PHENIX plans to accumulate the integrated luminosity of 300 pb^{-1} of $\sqrt{s} = 500$ GeV $p+p$ collision data for the W boson program.

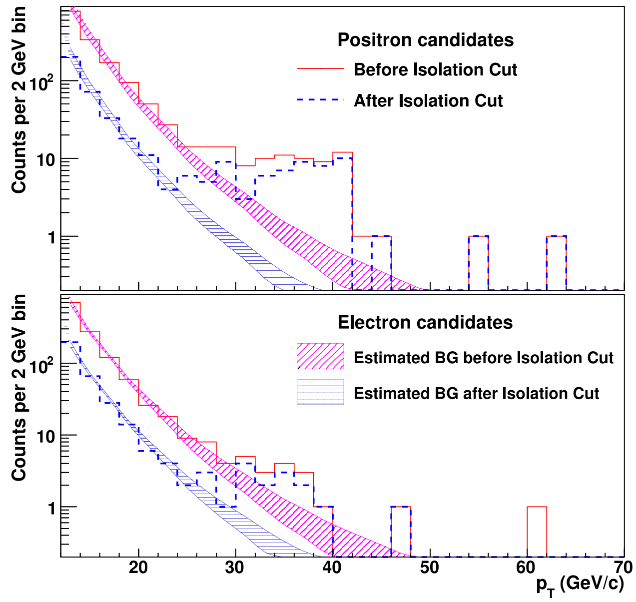

FIGURE 1. (color online) The spectra of positron (upper panel) and electron (lower panel) candidates before (solid histogram) and after (dashed histogram) an isolation cut. The estimated background bands are also shown.

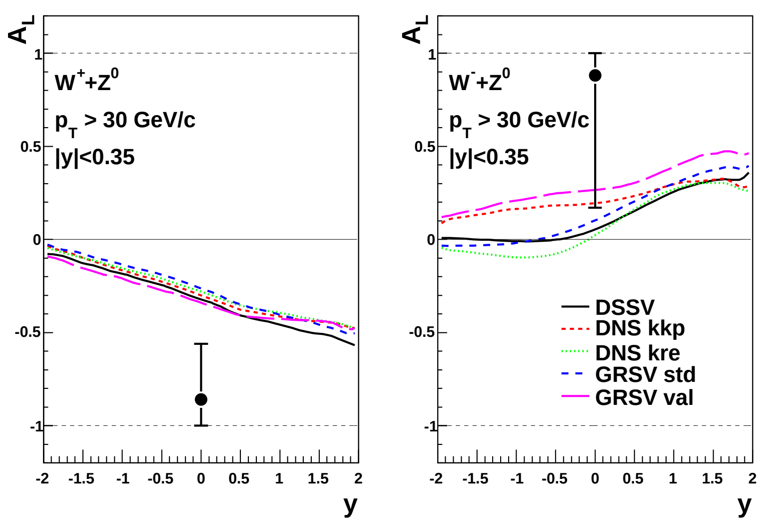

FIGURE 2. (color online) Longitudinal single-spin asymmetries for electrons and positrons from W and Z decays. The error bars represent 68% CL. The theoretical curves are calculated using NLO with different polarized PDFs.

ΔG MEASUREMENTS

The double longitudinal spin asymmetry (A_{LL}) of particle production is sensitive to the gluon spin content of the proton (ΔG). Based on the factorization scheme, ΔG can be extracted with inputs of the fragmentation function and the spin dependent partonic cross section. With high rate capability but relatively small acceptance, the PHENIX detector has an advantage in detecting single particle productions. PHENIX has measured A_{LL} of π^0, η[7], $\pi^{\pm}$[8], direct γ[9], and even jet production[10]. Among them the π^0 measurement at $\sqrt{s} = 200$GeV in the mid-rapidity made a large contribution to a global analysis of ΔG.

Mid-rapidity π^0 at $\sqrt{s}$ =200GeV

In the low p_T region where the yield is significant, the dominant partonic process of π^0 production is gluon-gluon scattering. The EMCal can produce a trigger signal with decay photons of π^0, and it can reconstruct π^0's mass from two photons with its high granularity. The spin asymmetry of the combinatorial background is measured using side bands of π^0's mass. Then it is subtracted from the asymmetry of the inclusive π^0 and combinatorial background. The purity goes up as the π^0 transverse momentum goes up. The double longitudinal spin asymmetry measurement from 2006 data set was reported [11] and was included in several global analyses to extract ΔG (e.g. [12]). According to the result, ΔG is small, consistent with zero within uncertainties. It is also proposed a possible node in $\Delta g(x)$. From the new 2009 data set of almost three times higher figure of merit (P^4L) than the 2006 data set, the A_{LL} was measured as a function of $p_T(\pi^0)$. Figure 3 shows the combined result. The data points overshoot the previous global fit result. It indicates a evidence of non-zero ΔG component. An effort to update the global fit is on-going.

Next steps

It is generally recognized that we need more measurements which are sensitive to lower partonic momentum fraction ($x_{BJ} <\sim 0.05$). In the low x_{BJ} region, the contribution to ΔG may be large. It is also important to obtain measurements of theoretically cleaner processes. For example, the direct photon production is dominated by the quark-gluon Compton scattering and sensitive to the sign of $\Delta g(x)$, while neutral pion production from gluon-gluon scattering is only sensitive to their product. The direct photon analysis is improving statistically. As shown in Fig. 4, it is more assured that the NLO pQCD calculation is applicable. However for this channel the asymmetry measurement is still statistically limited to significantly contribute the global analysis.

To go smaller x_{BJ}, there are two ways. One approach is to increase the collision energy. Compared to $\sqrt{s} = 200$ GeV, it can probe by a factor of 2.5 smaller x_{BJ} in $\sqrt{s} = 500$ GeV with the same p_T particle. Experimentally the measurement is more difficult in terms of triggering and handling the pile-up events. However this matches to

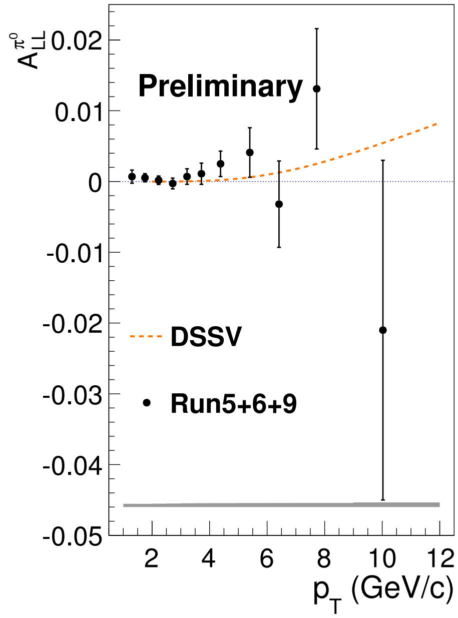

FIGURE 3. A_{LL} of mid-rapidity π^0 production in $\sqrt{s} = 200$ GeV (2005, 2006, and 2009 results are combined.) DSSV, a global fit result, doesn't include the 2009 data which is almost 3 times higher figure of merit (P^4L) than the 2006 data.

the RHIC operation for the W boson program. The asymmetry analysis of π^0 production in $\sqrt{s} = 500$ GeV is under way. The other approach is to study the forward particle production. It is sensitive to high x_{BJ} parton which is likely a quark in the projectile proton, and low x_{BJ} parton which is likely a gluon in the target proton. The MPC can detect electromagnetic showers. Figure 4 shows the measurement of π^0 production cross section from the MPC compared with the BRAHMS result in the forward region [13]. They agree with each other. As the π^0 energy goes up, decay photons can not be resolved in the MPC due to spatial resolution. But according to a Monte Carlo (MC) study, the majority ($\sim 80\%$) of electromagnetic clusters in the MPC is from π^0. Figure 6 shows a preliminary result of the double spin asymmetry of clusters in $\sqrt{s} = 200$ GeV. According to the leading order MC, it is sensitive to lower x_{BJ} down to 10^{-3}. By the end of W boson program, a decent amount of statistics is expected from the MPC clusters in $\sqrt{s} = 500$ GeV.

In the $2 \rightarrow 2$ process, the momentum fraction of the initial partons (x_1 and x_2) are determined by the rapidities of final state partons (y_1 and y_2) and the transverse momentum (p_T) with Equation 1. By requiring final state partons in high rapidities, it limits the kinematics and one of initial partons goes to low x_{BJ}.

$$x_1 = \frac{p_T}{\sqrt{s}}(exp(y_1) + exp(y_2)), x_2 = \frac{p_T}{\sqrt{s}}(exp(-y_1) + exp(-y_2)) \tag{1}$$

Selecting two leading particles in the MPC is an alternative of this constraint. From a event generator MC, when we require $p_{T,1} > 3$ GeV/c and $p_{T,2} > 1.5$ GeV/c in the

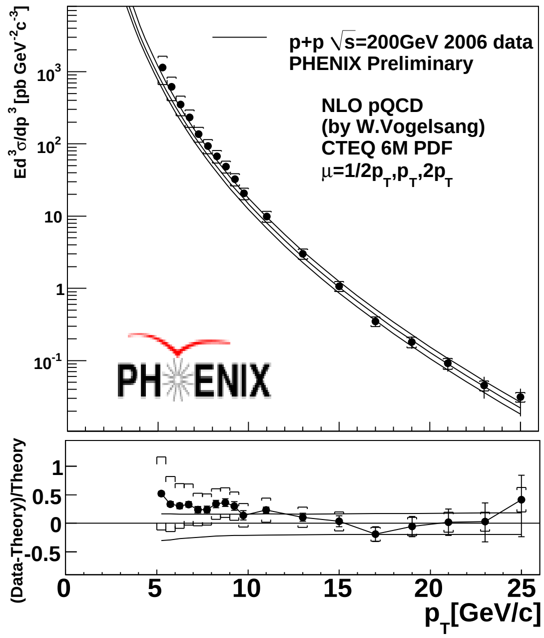

FIGURE 4. Updated mid-rapidity direct photon spectra in $\sqrt{s} = 200$ GeV from 2006 data.

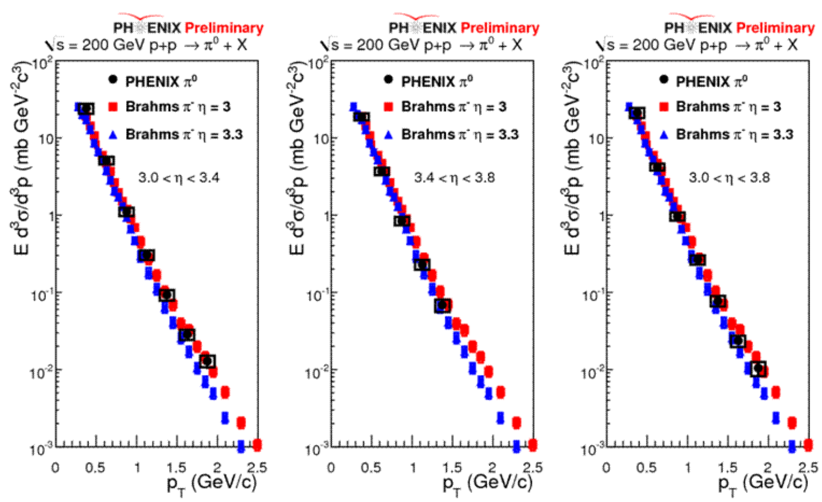

FIGURE 5. MPC π^0 cross section measurement compared with BRAHMS $\pi^{\pm}$ result. Left two plots show the different pseudo-rapidity range. The right plot shows a combined result.

MPC, the mean x_2 goes down to $\sim 4.8 \times 10^{-3}$. The drawback is it loses yields with the additional requirements.

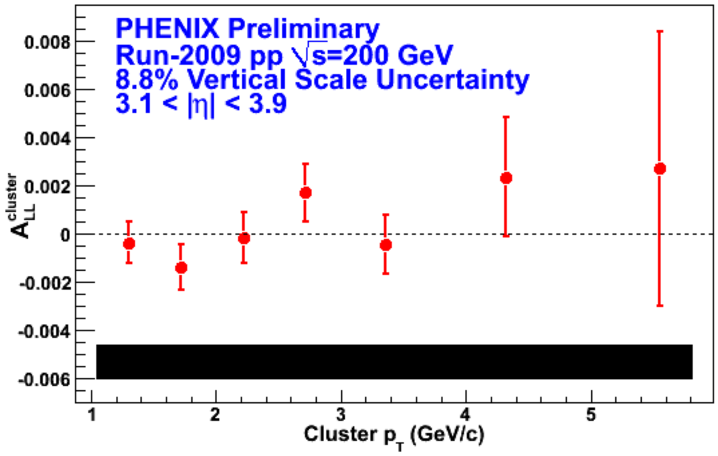

FIGURE 6. A_{LL} of MPC clusters (Mostly coming from π^0).

SUMMARY

RHIC has provided a unique opportunity of colliding high energy polarized protons. It is a complementary approach to the deep inelastic scattering experiment in order to understand the structure of the proton spin. The capability of real W boson allows us to access anti-quark flavor dependent decomposition without the involvement of any fragmentation function, and at a high energy scale guaranteed by the mass of W boson. PHENIX reported the first measurement of W boson production with its electron (positron) decay channel. For the next few years, more integrated luminosity will be accumulated. Mainly from the A_{LL} measurement of π^0 production in the mid-rapidity region in $\sqrt{s} = 200$ GeV, ΔG turned out to be small, consistent with zero within uncertainties. However the new result from 2009 data seems to disagree with the current global fit result. There might be a hint of non-zero ΔG evidence.

The ΔG measurements in the PHENIX mid-rapidity is close to the end of the first stage. Currently we put an effort to expand lower x_{BJ} region with forward MPC detector. Discussions for PHENIX upgrade have started. The direction is to enlarge the acceptance in both mid and forward rapidity regions [14]. The change of the PHENIX concept is favored by both the heavy ion physics and the spin physics. For the spin physics, the large acceptance allows us to accumulate more yields, more efficient algorithm of direct photon isolation cut, and by reconstructing away side activity it enables us to constrain the kinematics. The coverage of the forward rapidity region is also productive for the transverse spin topics.

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